

NIR view on young stellar clusters in nearby spirals

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Abstract

Observations in the near-infrared (NIR) allow a detailed study of young stellar clusters in grand-design spiral galaxies which in visual bands often are highly obscured by dust lanes along the arms. Deep JHK-maps of 10 spirals were obtained with HAWK-I/VLT. Data for NGC 2997 are presented here to illustrate the general results for the sample.

The (H-K)–(J-H) diagrams suggest that most stellar clusters younger than 7 Myr are significantly attenuated by dust with visual extinctions reaching 7^m. A gap between younger and older cluster complexes in the (J-K)–M_K diagram indicates a rapid reduction of extinction around 7 Myr possibly due to expulsion of dust and gas after supernovae explosions. The cluster luminosity function is consistent with a power law with an exponent $\alpha \approx 2$. Cluster luminosities of M_k = –15^m are reached, corresponding to masses close to 10⁶ M_⊙, with no indication of a cut-off. Their azimuthal angles relative to the main spiral arms show that the most massive clusters are formed in the arm regions while fainter ones also are seen between the arms. Older clusters are more uniformly distributed with a weaker modulation relative to the arms.

1 Introduction

Many grand-design spirals have strings of knots along their arms on NIR maps. Such knots have been identified as complexes of very young stellar clusters (Grosbøl et al. 2006) which may have been triggered by a star-formation front associated with a spiral density wave (Lin & Shu 1964; Roberts 1969). The usage of NIR bands for the analysis of clusters provides two main advantages: a much more complete census of young clusters, often embedded in dust lanes, and age estimates for clusters younger than 7 Myr.

A sample of 10 grand-design, spiral galaxies with a range of Hubble types were selected from the study by Grosbøl & Dottori (2008) and observed in the NIR to study possible relations between spiral perturbations and star-formation. In this paper, we will only present results for NGC 2997 as a representative for the full sample.

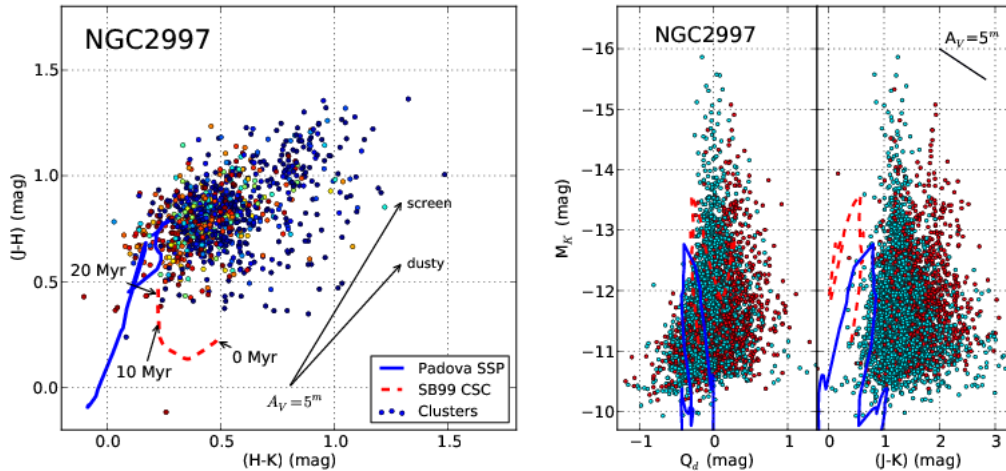


Figure 1: Color-color and color-magnitude diagrams for non-stellar sources in NGC 2997.

2 Data

Deep maps of the galaxies were obtained in JHK-bands with the HAWK-I/VLT instrument which provides a $7'$ field with $0.1''$ pixels. NGC 2997 is classified as Sc(s)I.3 and has an oval distortion in its central parts outside which a grand-design, two-armed spiral structure with a pitch angle of 21° is seen. Its distance was assumed to be 19.2 Mpc derived from its velocity relative to the 3K-CMB and a Hubble constant of 73 km/s/Mpc. The reduced, stacked images had a seeing of $0.4''$ which translates to a linear resolution of ≈ 40 pc at the distance of NGC 2997.

More than 5300 sources were identified on the K-band image of NGC 2997 using *SExtractor* (Bertin & Arnouts 1996). The photometric zero points were established through the 2MASS photometry (Skrutskie et al. 2006) of foreground stars in the field. The limiting magnitude was estimated to $K_l = 20.1^m$ (i.e. $M_K = -11.3^m$) for 90% completeness depending on the local crowding. Individual stellar clusters cannot be resolved with the resolution of 40 pc making it likely that many non-stellar sources are complexes of clusters or star-forming regions.

3 Color and magnitude diagrams

The general properties of the sources can be deduced from the color-color and color-magnitude diagrams as given in Fig. 1. The (H-K)–(J-H) diagram for sources with photometric errors $< 0.05^m$ shows a main group centered around (0.4, 0.8) being consistent with colors of somewhat reddened, stellar clusters with ages > 50 Myr. Evolutionary tracks for a single-burst stellar population (SSP) using the Padova isochrones (Marigo et al. 2008) and a continuous star-forming cluster (CSC) from Starburst99 (Leitherer et al. 1999, hereafter SB99) are indicated on the figure. The reddening vectors for a screen model (Indebetouw et al. 2005) and a dusty environment (Witt et al. 1992; Israel et al. 1998) are also plotted for a visual extinction of 5^m . A second, smaller group is located close to (0.8, 1.1) which is likely to

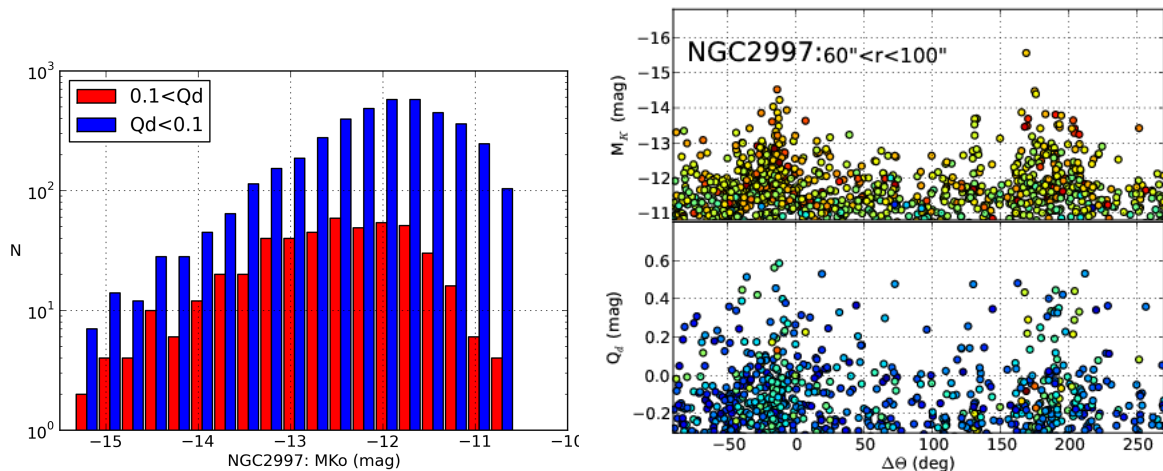


Figure 2: Luminosity function (left) and azimuthal distribution relative to the main two-armed spiral in the radial region $60'' - 100''$ (right) of cluster complexes in NGC 2997.

contain highly reddened, dusty young clusters. Finally, there is a scatter of sources to redder (H-K) values which may be caused by emission from hot dust. Whereas many older cluster has small extinction, most young complexes have several magnitudes of visual extinction.

A reddening correction color index $Q_d = (H-K) - 0.84 \times (J-H)$ can be constructed using the dusty models of Witt et al. (1992). The color-magnitude diagrams for the absolute magnitude M_K is shown on the right in Fig. 1 as functions of Q_d and (J-K) indexes. Tracks of evolutionary SSP models are indicated on the figures together with a dusty reddening vector. The Q_d - M_K diagram is consistent with the tracks with some (H-K) excess due to hot dust and absolute magnitudes up to $M_K \approx -15^m$ corresponding to masses of the order of $10^6 M_\odot$ with a Salpeter IMF and an upper mass limit of $100 M_\odot$. The (J-K) plot shows a double branch structure where the redder one with $(J-K) = 1.9^m$ consists of the young, dusty clusters in the color-color diagram while the older clusters are located around 1.2^m . From the evolutionary tracks, it is expected that intrinsic (J-K) colors of clusters become redder with age. The gap between the two branches suggests a rapid reduction of extinction in the clusters which may be caused by expulsion of dust and gas due to supernovae explosions.

4 Luminosity and spatial distribution

The attenuation by dust can be estimated from the (H-K)-(J-H) diagram using the SB99 model track for the intrinsic colors. Applying this correction, the distribution of the 'reddening free' absolute magnitude M_{Ko} is shown in Fig. 2 where the sources are separated in young complexes with $0.1^m < Q_d$ (i.e. age < 7 Myr) and older ones. Incompleteness starts to be important at $-12^m < M_{Ko}$ for the older population while the young one is affected already around -13^m due to their higher average extinction. The high luminosity part of both samples follows a power law with almost the same exponent $\alpha = 2.1$ and no significant indication of a cut-off at brightest magnitudes. The ratio between the two populations varies significantly from galaxy to galaxy in the sample and reflects the current star-formation rate relative to

the average.

The main symmetric part of the spiral pattern in NGC 2997 starts around $60''$, just outside the oval distortion, and breaks up close to $100''$. The phase of the arms in this region was determined from the $m=2$ Fourier component of the azimuthal K-band intensity variation in $1''$ radial bins. Absolute magnitude M_K and color index Q_d of complexes are plotted as function of their azimuthal angle $\Delta\Theta$ relative to the main arms in the right panel of Fig. 2. The M_K values are clearly peaked in the arm regions (i.e. around 0° and 180°) with very few source brighter than -13^m between the arms. A similar picture is seen for $\Delta\Theta$ - Q_d diagram where young complexes with $0.1^m < Q_d$ are more frequent in the arms although some fainter clusters are formed in between the arms. Older, fainter complexes are more uniformly distributed with only a moderate increase in density in the arm regions.

5 Conclusions

In a sample of 10 nearby grand-design, spiral galaxies, NGC 2997 was selected to illustrate the general properties of their stellar cluster populations as observed in the NIR. The cluster complexes form two distinct groups in the (H-K)–(J-H) diagram where the larger is consistent with an older stellar population with low extinction while the smaller mainly contains of young complexes with ages < 7 Myr and visual extinctions in the range $2-7^m$. No young cluster with $A_V < 1^m$ was found while some are scattered to redder (H-K) colors possibly by emission from hot dust. A gap between older and younger complexes in (J-K)- M_K diagram suggests a rapid expulsion of dust at an age around 7 Myr which could be triggered by supernovae explosions.

The upper part of the cluster luminosity function is well fitted by a power law with an index $\alpha \approx 2$ with no indication of a cut-off at the bright end. The most luminous complexes with M_{K0} around -15^m may have masses close to $10^6 M_\odot$ assuming a Salpeter IMF. The distribution of sources relative to the spiral arms indicates that the most massive clusters predominantly are formed in the arm regions while fainter and older cluster show a more uniform azimuthal distribution with a weaker modulation relative to the arms.

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